Observing a light dark matter beam with neutrino experiments

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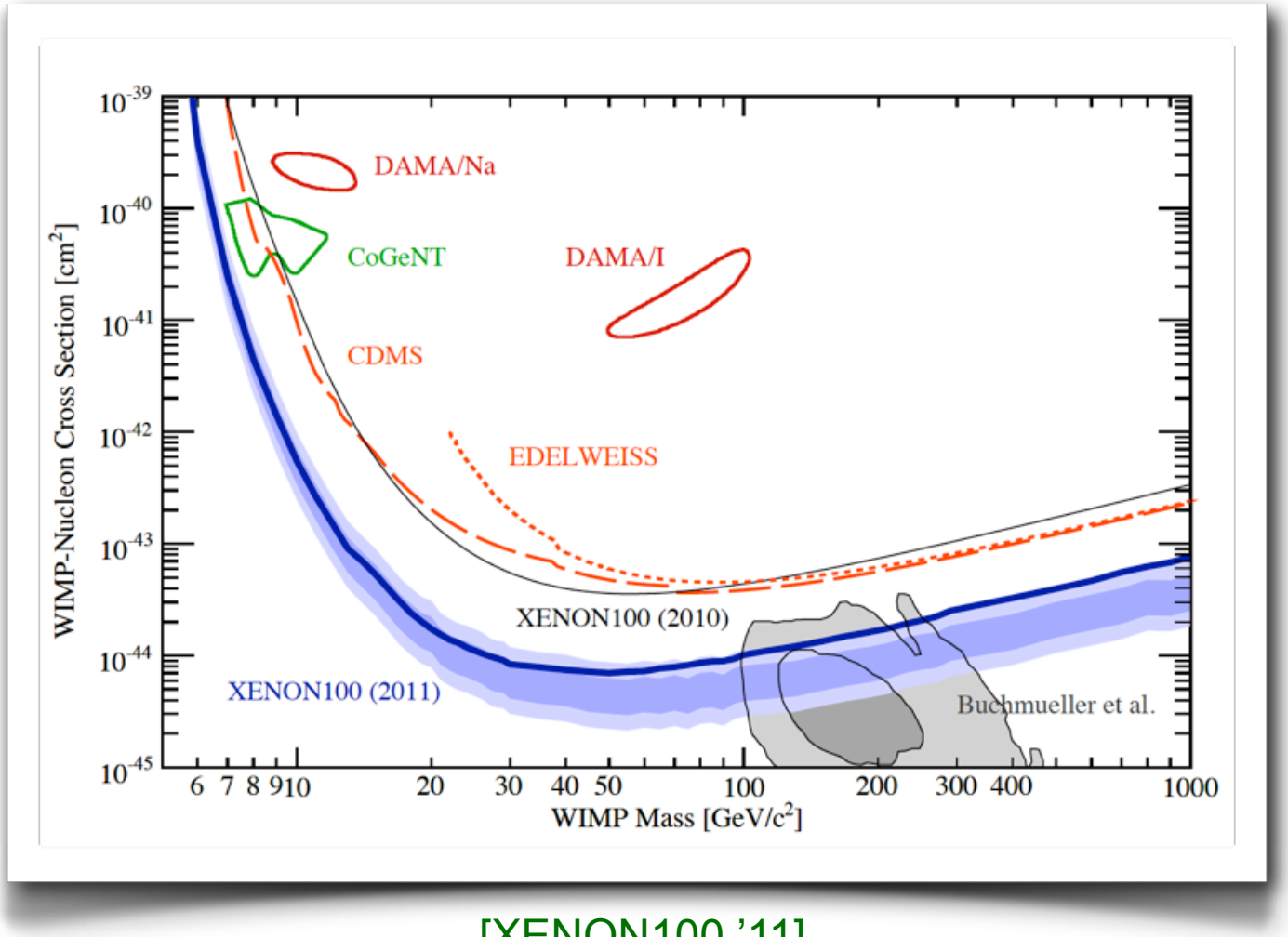
with P. deNiverville and M. Pospelov,

1107.4580

Direct probes of (very) light dark matter?

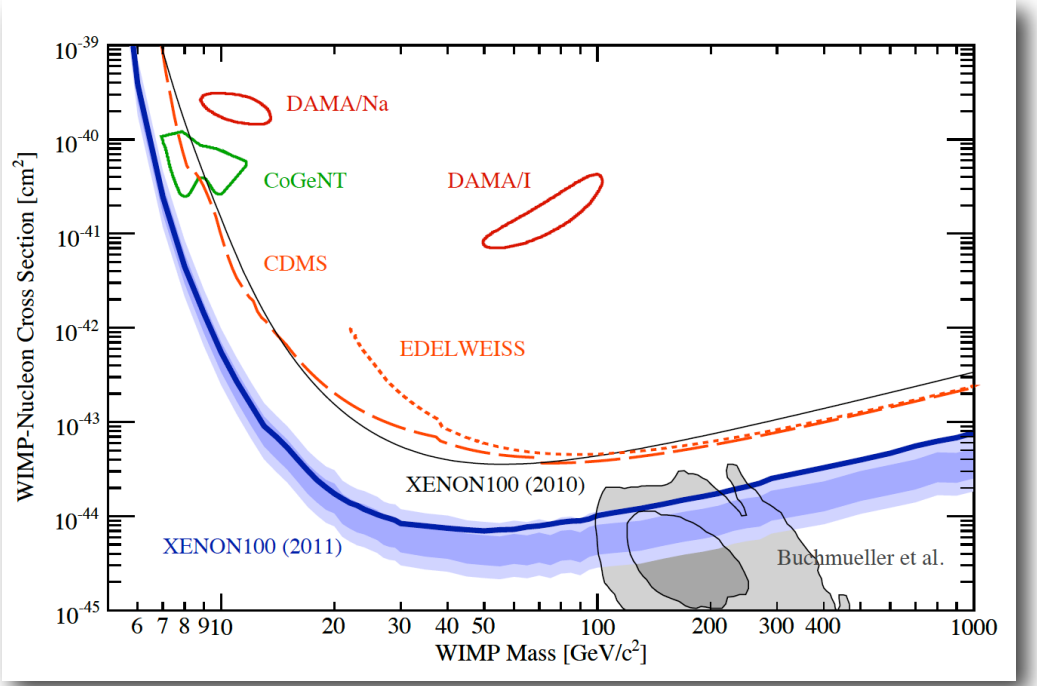


[XENON100 ’11]

Direct probes of (very) light dark matter?

σ_{scat}

- Recoil signal too weak, given $v \sim 10^{-3}$
- Need a relativistic beam!

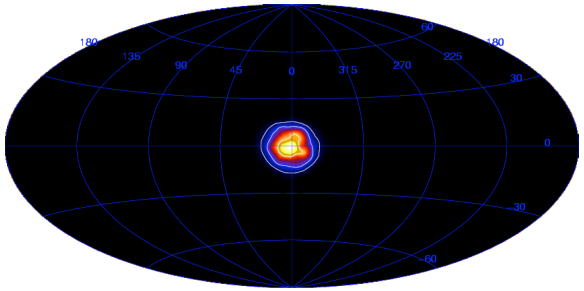


$m_{electron} - m_{hadron}$

m_{DM}

Light WIMPs - some early motivation

An older positron anomaly...



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- 511 keV line, with diffuse source around the galactic center [INTEGRAL/SPI '03-'07].
- suggestive at the time of DM annihilation *[...however a disk component now observed [INTEGRAL/SPI '08]].*

Need "cold" positron source, E < 3 MeV [Beacom & Yuksel '05], motivating studies of MeV-scale DM, below the Lee-Weinberg bound [Boehm et al '03, Fayet '04,'07].

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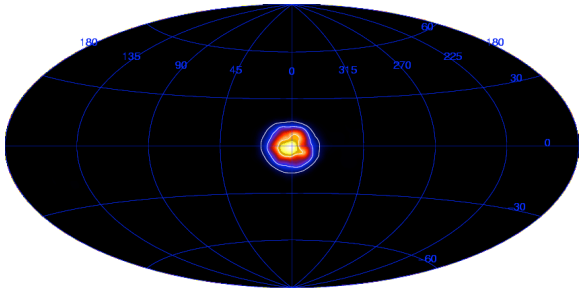

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⇒ viable thermal relic density requires new annihilation channels through light states, i.e. light DM as part of a hidden sector.

Standard Model ⟷ Hidden Sector

Light mediators

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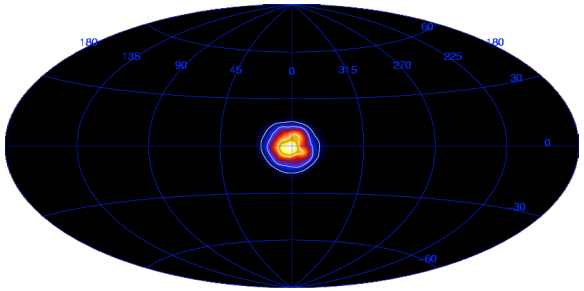

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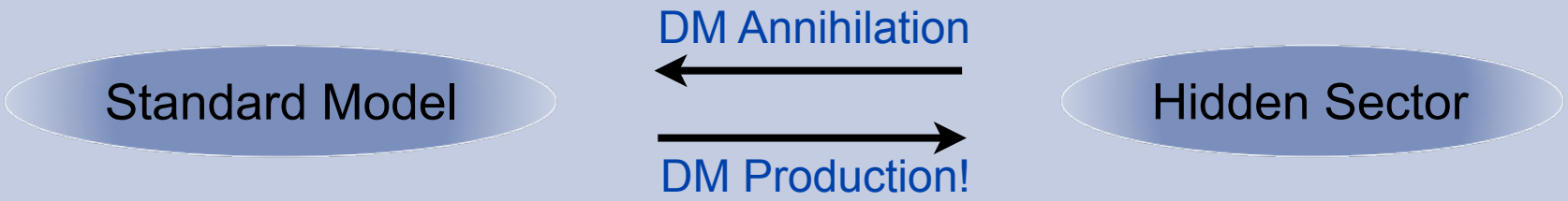
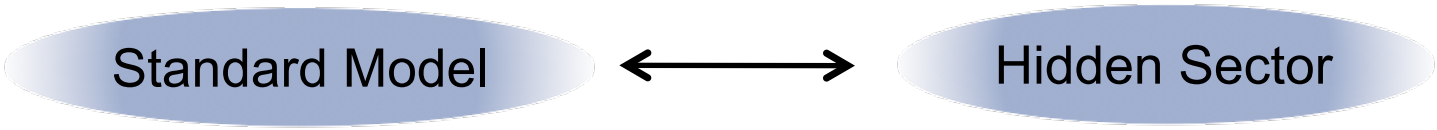


➪ by inversion, light mediators allow direct production of DM at ***low energy!***

Probing DM in a light hidden sector



$$\mathcal{L}_{med} = \sum_{n,k,l}^{n=k+l-4} \frac{O_k^{(SM)} O_l^{(med)}}{\Lambda^n}$$

Generic interactions are irrelevant (dimension > 4), but there are three renormalizable "portals"

- Vector portal: $\mathcal{L} = -\frac{\kappa}{2} V^{\mu\nu} B_{\mu\nu}$
- Higgs portal: $\mathcal{L} = (-\lambda S^2 + \xi S) H^\dagger H$
- Neutrino portal: $\mathcal{L} = -y_{ij} \bar{L}_i H N_j$

MeV-scale DM

Classes of MeV-scale models

[Boehm et al '03; Fayet '04,'06; Pospelov, AR, Voloshin '07]

$$\frac{\Omega_{\rm DM}}{\Omega_{\rm m}} \simeq (2-4)\frac{1\,{\rm pbn}}{\langle\sigma v\rangle_{\rm fo}}$$

$$\frac{\Phi_{511,{\rm DM}}}{\Phi_{511,{\rm tot}}} \sim \frac{\langle\sigma v\rangle_{\rm gal}}{10^{-40}\,{\rm cm}^2} \times \left(\frac{1\,{\rm MeV}}{m_{\rm DM}}\right)^2 \times \left(\frac{\Omega_{\rm DM}}{\Omega_{\rm m}}\right)^2$$

- U(1) mediator

  - $m_{DM} > m_V$: s-wave annihilation, so can only explain 511 keV flux if a highly subdominant component of DM

  - $m_{DM} < m_V$: A scalar DM candidate has p-wave annihilation, and is viable for $\kappa \sim 10^{-4}$ -10^{-3}

- Scalar mediator

  - $m_{DM} > m_\phi$: A fermionic DM candidate has p-wave annihilation and can be viable, but needs significant tuning to avoid limits from missing-energy K decays.

  - $m_{DM} < m_\phi$: Annihilation is suppressed, and would require O(1) mixing which is ruled out e.g. by K and B decays.

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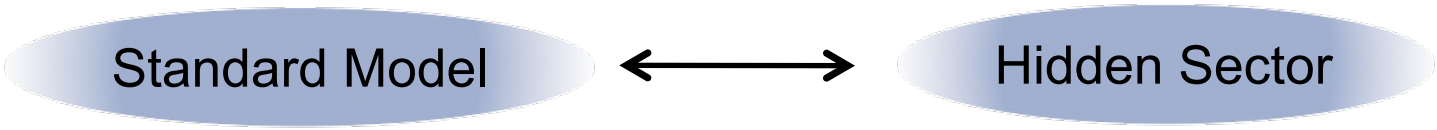

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NB: The vector mediator V can naturally be light (M << M_Z)

MeV DM coupled via the U(1) portal

$$\mathcal{L} = -\frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{2}V_{\mu\nu}F^{\mu\nu} - \frac{1}{2}m_V^2 V_\mu^2 + |D_\mu\chi|^2 - m_{\rm DM}^2|\chi|^2 + \cdots$$

$$\mathcal{L}_{\rm int} = -\kappa e V_\mu J^\mu_{\rm em}$$

V - production through mixing with EM current: $O(\kappa^2)$

DM candidate, coupled through U(1)'

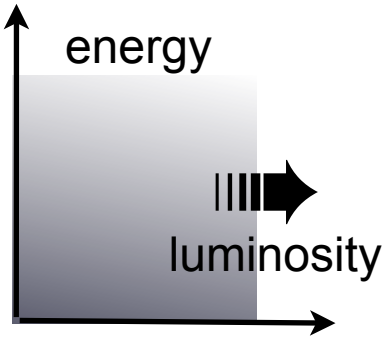
- Viable thermal relic DM candidates at an MeV [Boehm et al '03, Fayet '04,'06; Pospelov, AR, Voloshin '07; Hooper & Zurek '08]. [NB: Weak-scale candidates of interest due to enhanced low-v annihilation [Finkbeiner & Weiner, '07; Pospelov, AR, Voloshin '07; Arkani-Hamed et al '08; Pospelov, AR '08].]
- For $m_{DM} < m_V$, the correct relic density fixes a specific relation between $\{\alpha', m_V, m_{DM}, \kappa\}$ [Pospelov, AR & Voloshin '07] and we also require perturbativity of the U(1) coupling α' (e.g. $\alpha' \sim \alpha$).

Experimental Sensitivity

Astrophysical Sensitivity (other than galactic annihilation)

- CMB - ✘ - as annihilation is p-wave [Padmanabhan & Finkbeiner et al '05; Slatyer et al '08]
- SN - ✘ - due to thermalization in the core
- BBN - ✘ - minimal impact for m > 1 MeV [Serpico & Raffelt '04]

Particle Physics Sensitivity (other than direct nuclear recoil)

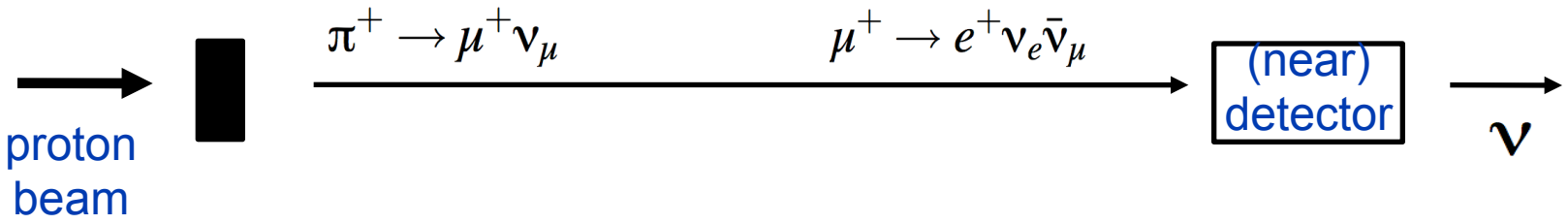


- Correction to g-2 - ✔ [Pospelov '08]
- Dark Force Searches, V➔e^+e^- - ✘ - as Br(V ➔DM)~1
  [Bjorken et al. '09; Batell et al '09; Reece & Wang '09; MAMI '11, APEX '11, ...]

- ∉ in rare decays (eg Kaons) - ✔ [Fayet '06, '09; Pospelov, AR & Voloshin '07]
- ∉ at colliders - B-factories (O(ab^{-1}) datasets) - ✔ [Borodatchenkova et al '06]
  - LEP, LHC - ✔ [see SUSY'11 talks by Harnik, Tsai, Tait]

and • Fixed targets/Neutrino detectors - this work!

Fixed target probes - Neutrino Beams



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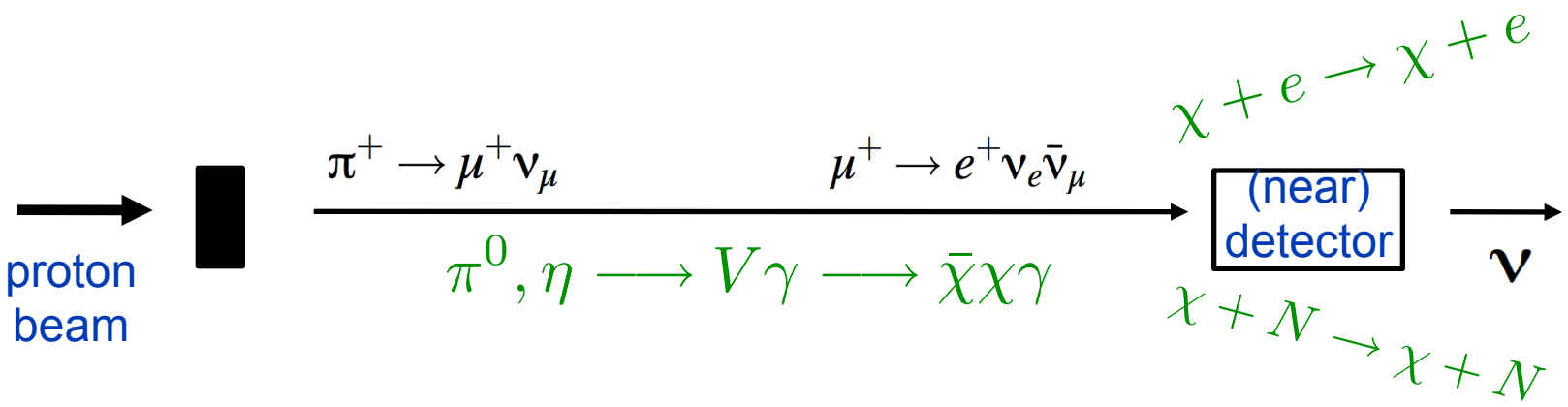

Thus we can use the neutrino (near) detector as a dark matter detector, looking for recoil, but now from a relativistic beam.

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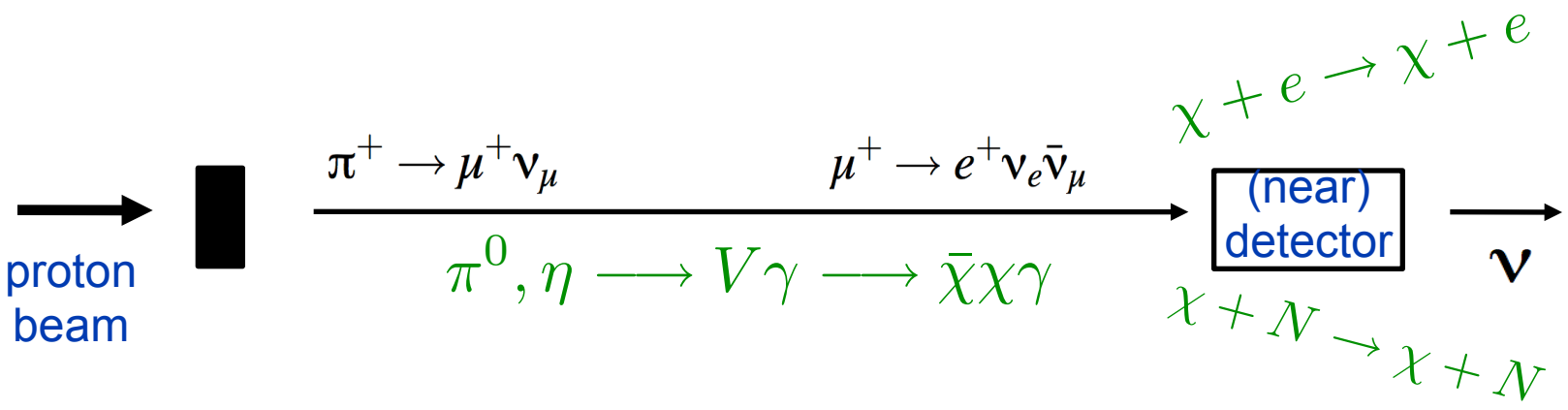


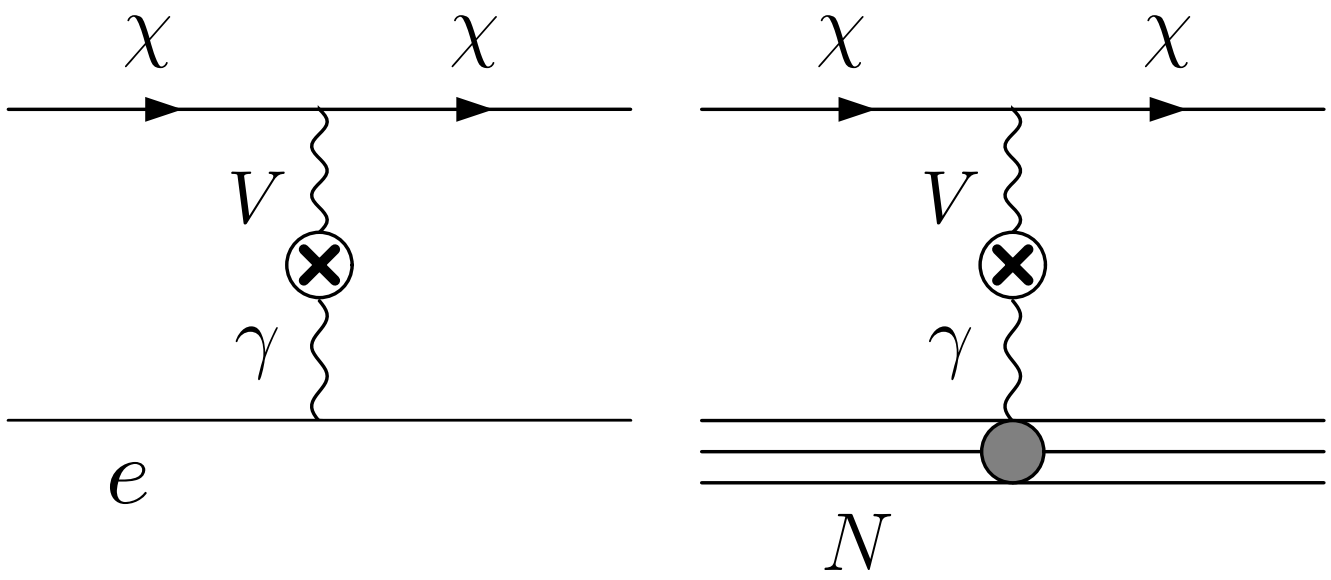
Thus we can use the neutrino (near) detector as a dark matter detector, looking for recoil, but now from a relativistic beam. E.g.

LSND
800 MeV protons
10^{23} POT
30m to (~200m^3)
mineral oil target

MiniBooNE
8.9 GeV protons
10^{21} POT
540m to (~300m^3)
mineral oil target

Signatures

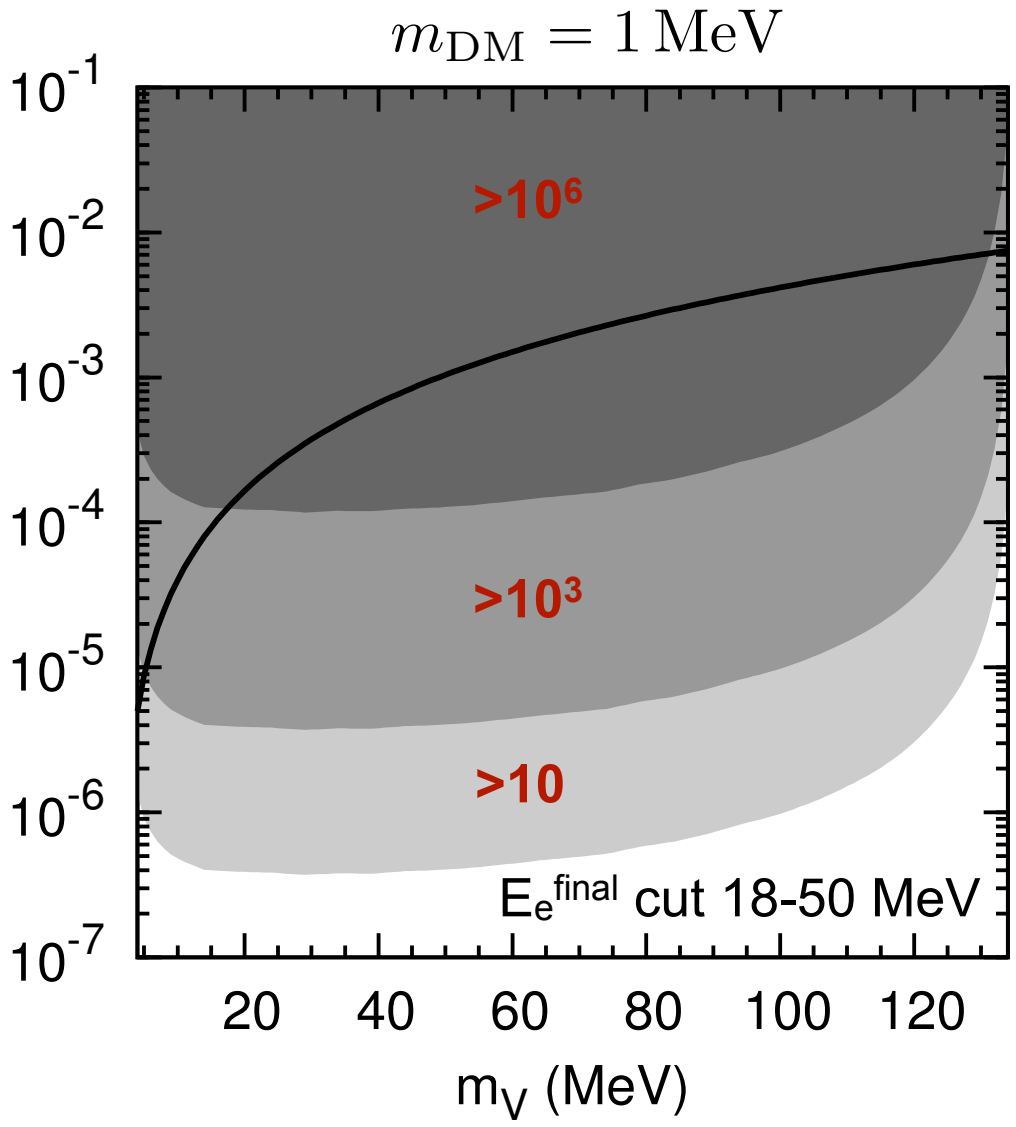
Characteristic DM elastic scattering signatures



These processes mimic neutral current elastic scattering of neutrinos, and thus can lead to an observable excess.

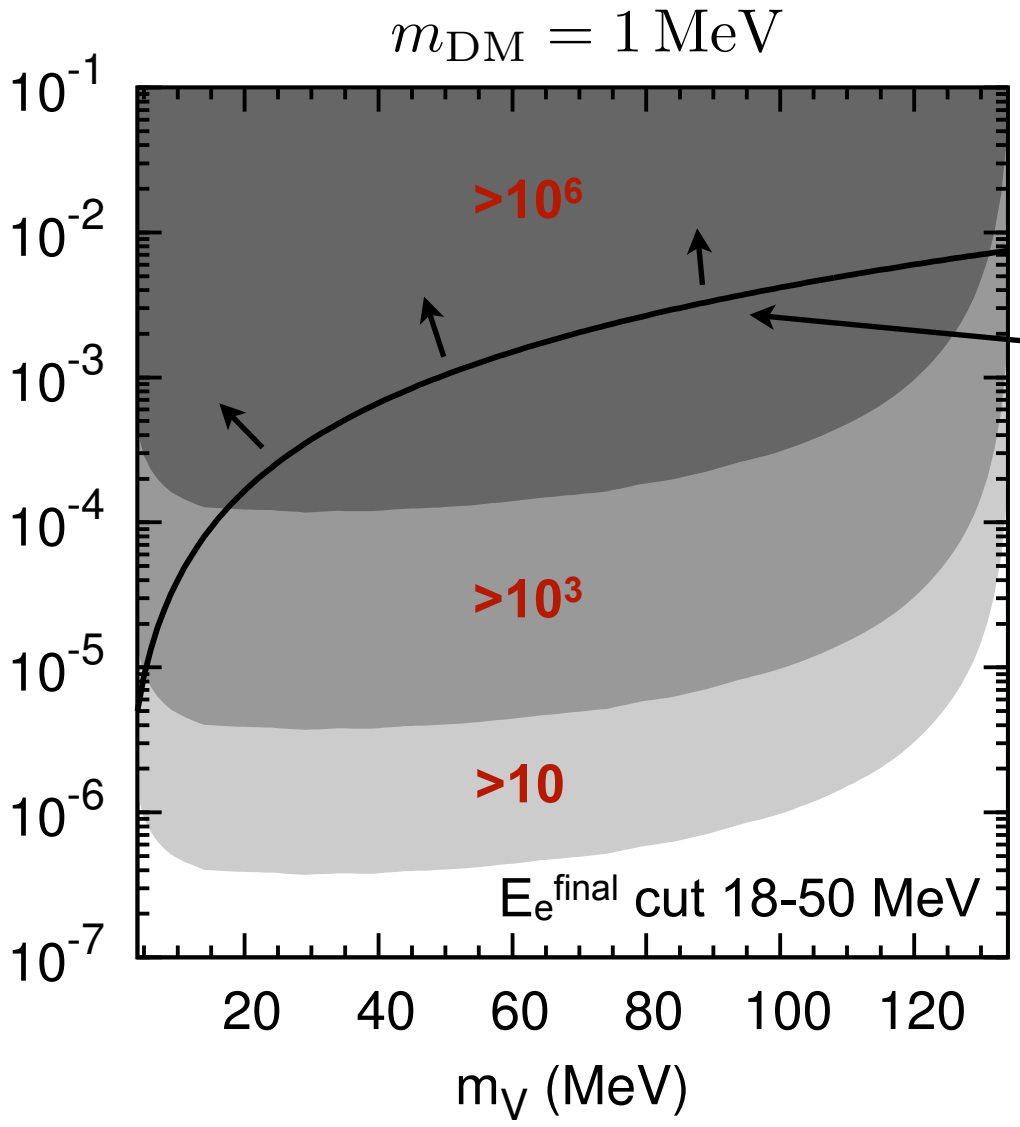
Results

via $\pi^0 \rightarrow \gamma V$



Background at LSND is ~300 Elastic Scattering events [LSND '01]

Results



via $\pi^0 \rightarrow \gamma V$

perturbativity constraint required for relic density & an explanation of 511 keV line (shifts lower for higher m_{DM})

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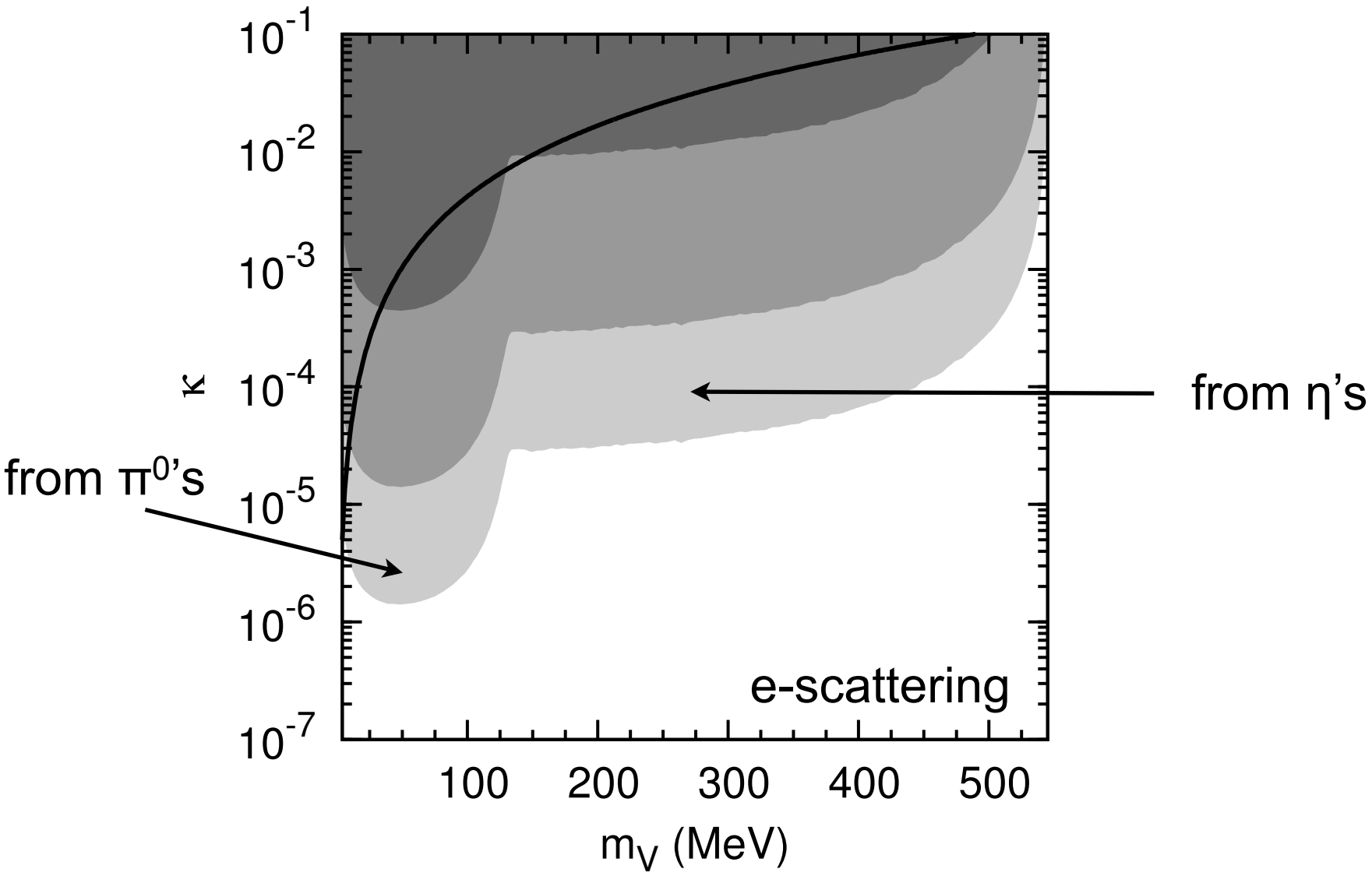
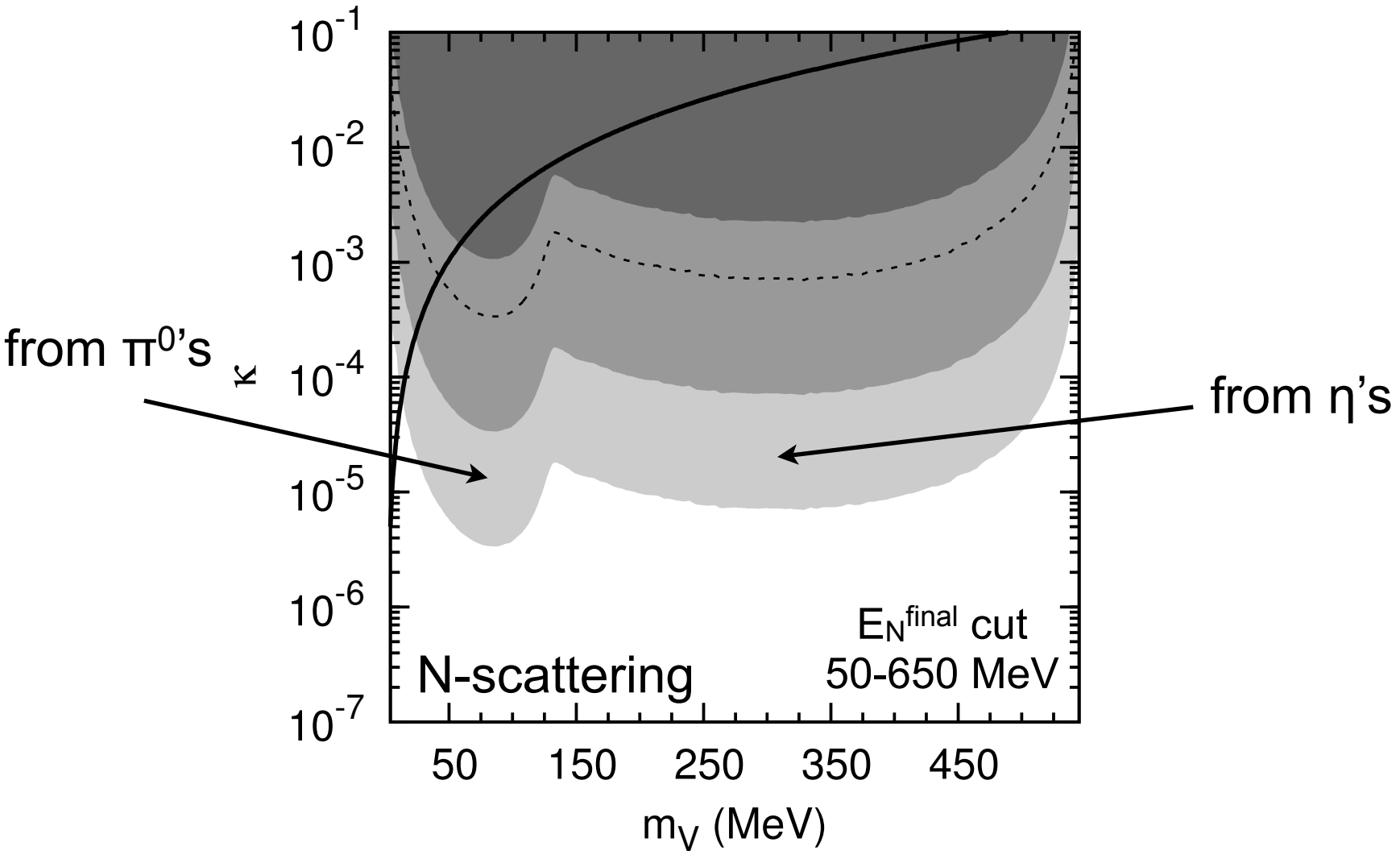


Production of η's at MiniBooNE leads to a significant increase in mass reach

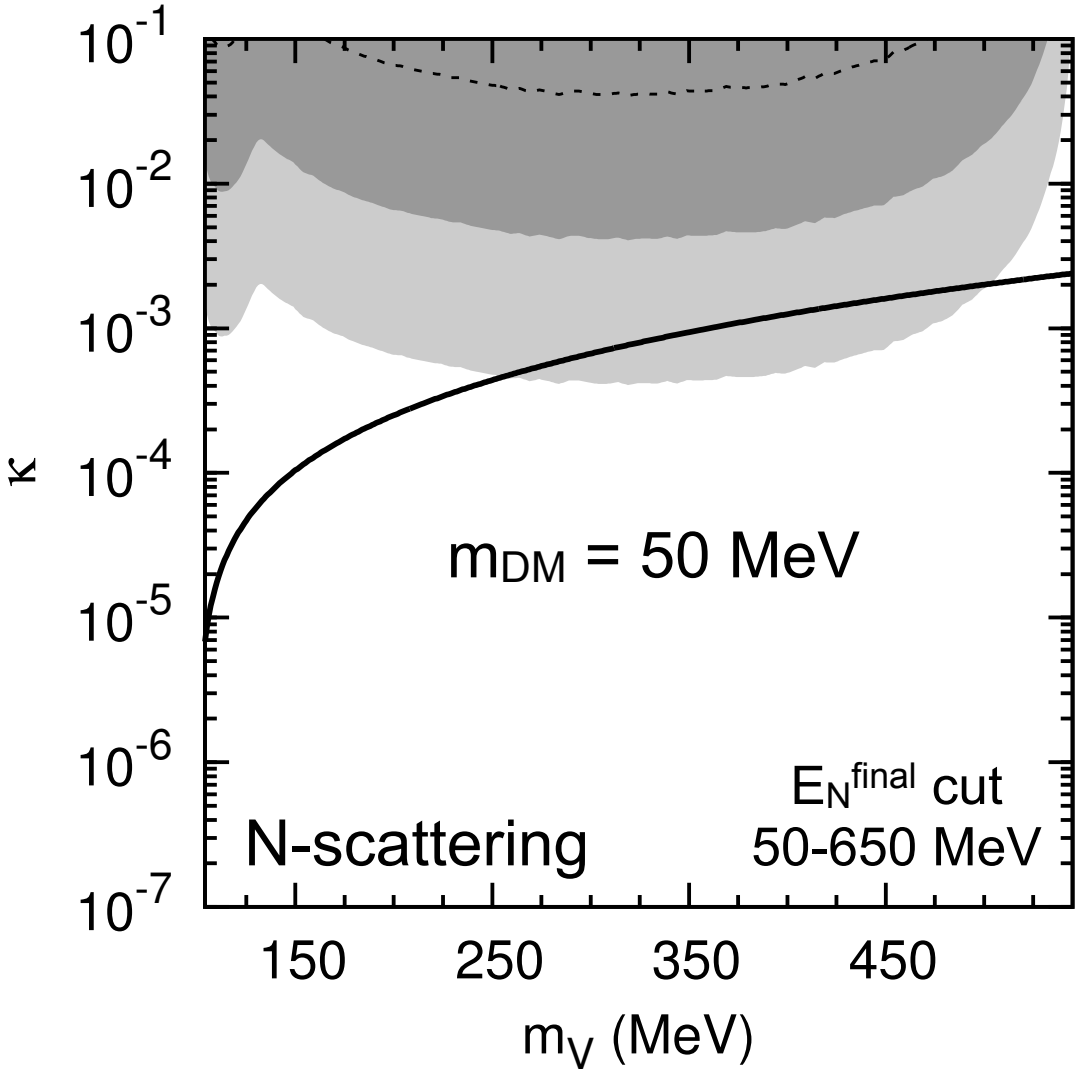
Results



Better sensitivity, but (naive) background is ~ 6×10^4 NC neutrino events

[MiniBooNE '10]

Results



Still have sensitivity at higher mass, but much lower S/B

[MiniBooNE '10]

Concluding Remarks

Summary

- A neutral hidden sector is an intriguing possibility, motivated by dark matter, RH neutrinos, SUSY breaking, …

  - Allows for thermal relic DM in the MeV-GeV range
  - Models coupled via the vector portal (and others) can be tested at the luminosity frontier, particularly through fixed-target neutrino facilities.
  - Limits from LSND and MiniBooNE rule out a class of MeV-scale models motivated by the galactic 511 keV line.

Further tests

- Significant sensitivity to MeV-GeV scale new physics from neutrino sources: LSND, MiniBooNE, NuMI/MINOS, T2K, NOvA, CLEAR, ...

  - Increased mass range, different mediators, ...